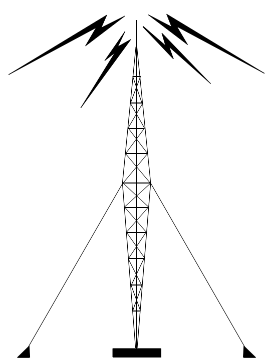
Federal Communications Commission
Office of Engineering & Technology

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

Additional Information for Radio and Television Broadcast Stations



Supplement A
(Edition 97-01)
to
OET Bulletin 65 (*Edition 97-01)*

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

Additional Information for Radio and Television Broadcast Stations

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Edition 97-01
to
OET BULLETIN 65
Edition 97-01

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INTRODUCTION

This supplement is designed to be used in connection with the FCC's OET Bulletin 65, Version 97-01. The information in this supplement provides additional detailed information that can be used for evaluating compliance of radio and television broadcast stations with FCC guidelines for exposure to radiofrequency electromagnetic fields. However, users of this supplement should also consult Bulletin 65 for complete information on FCC policies, guidelines, compliance-related issues and methods for achieving compliance.

NOTE: The first edition of Bulletin 65 was issued as OST Bulletin No. 65 in October 1985. This supplement contains broadcast-related information and data that have been revised from that which was included in the original bulletin.

SECTION 1
AM Radio Broadcast Stations

In determining compliance with limits for Maximum Permissible Exposure (MPE) for AM radio broadcast stations, it is normally most important to determine electric and magnetic field strength at distances relatively close to transmitting antennas. Fields from these monopole antennas decrease relatively rapidly with distance, and MPE limits for AM radio frequencies are not as restrictive as those for other frequencies, such as those used for FM radio. Therefore, even for the highest powered stations, MPE limits for AM radio transmissions would normally only be exceeded relatively close to antennas. Compliance with the FCC's guidelines for AM stations typically will involve assessment of exposure potential of persons working or occupying areas in the close-in vicinity of transmitting antennas. Because such persons will always be in the near field of AM antennas, due to the relatively long wavelengths in the AM frequency band, an evaluation of both electric and magnetic field strength is necessary.

In the original version of OET Bulletin 65, staff from the U.S. Environmental Protection Agency (EPA) provided the FCC with results from a computer-based model to help determine compliance with MPE limits for AM radio broadcast stations. The EPA model used the Numeric Electromagnetic Code (NEC) computer program to predict field-strength levels near AM monopole antennas. In the past several years a PC-based version of this code, called MININEC, has also become available. The FCC has used MININEC to expand and refine the predictions for electric and magnetic field-strength presented in the original version of Bulletin 65. They are included in this supplement in the form of tables and figures that can be used in evaluating compliance at these stations.

Tables 1-4 may be used to determine the minimum distance from an AM broadcast antenna to the point where electric and magnetic field strengths are predicted to correspond to MPE limit values. The tables provide compliance distances from antennas of various electrical heights transmitting at various frequencies and using various power levels. The distances specified are the distances from an antenna at which access should be restricted in order to comply with ***both*** the electric and magnetic field-strength MPE limits. For antennas that do not correspond to the specific conditions given in these tables, interpolation can be used to arrive at intermediate values, or, alternatively, the greatest distance for the range used for interpolation could be used.

Since the MPE limits for the two exposure tiers are similar for most AM frequencies, and because of variability in compliance distances according to electrical height and operating frequency, one entry is given in each case that applies for both occupational/controlled and general population/uncontrolled exposures. These numbers represent the minimum worst-case distances predicted for compliance with the strictest MPE limit for each case. Note that timeaveraging considerations are not taken into account in these computations. Continuous exposure is assumed in all cases.

This model computes field strength values in the vicinity of single antennas. For AM stations with multiple-tower arrays a conservative "worst case" prediction could be made by assuming that ***all*** transmitted power is radiated from each antenna. Therefore, in such cases the appropriate value from the tables could be used to define a zone of restriction around the array, consisting of circles with equal radii, each of which is centered around a tower in the array. Alternatively, a more accurate prediction could be made if the power actually radiated by each tower is known.

It may be necessary to predict electric and magnetic field-strength at various locations in the vicinity of AM antennas. Therefore, Figures 1-4 have been developed for this purpose using MININEC. These figures show conservative predictions of electric and magnetic field-strength versus distance from typical AM broadcast antennas for towers with electrical heights equal to 0.1, 0.25, 0.5, and 0.625 wavelengths, respectively.

Figures 1-4 predict field strength for stations transmitting with 1 kilowatt of power. Therefore, for stations operating at other power levels values obtained from these figures should be multiplied by the square root of the station's power. The following example illustrates the proper procedure. In this example a 50 kilowatt AM station is located near a publicly accessible area. It is desired to obtain an estimate of the field-strength levels in this area which is at a distance of 10 meters from the station's single tower that has an electrical height of 0.25. To arrive at the estimated field strength values proceed as follows:

- ✓ **Consult Figure 2 for an antenna with electrical height = 0.25**
- ✓ **At 10 meters read predicted electrical field-strength = about 8 V/m**
- ✓ **At 10 meters read predicted magnetic field-strength = about 0.06 A/m**
- ✓ **Multiply each value by** $\sqrt{50}$
- ✓ **Predicted values are 56.6 V/m and 0.42 A/m**

As discussed in Section 4 of Bulletin 65, RF currents will be induced in the body of persons who climb transmitting AM broadcast antennas for maintenance or other purposes. This is a significant source of RF exposure and can be related to the limits for specific absorption rate (SAR) adopted by the FCC.[1] Although many stations may prefer to shutdown power entirely while persons are climbing their antennas, in some cases this may be difficult or undesirable. Studies have been undertaken by the FCC and the EPA to determine

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[1] SAR is discussed in Section 1 of Bulletin 65.

appropriate operating power levels which should allow climbing of transmitting AM antennas without exceeding the SAR guidelines.[2] The results of these studies were used to develop Figure 5, which shows operating power levels versus frequency for a variety of different electrical heights that are predicted to allow tower climbing without exceeding the exposure guidelines in terms of SAR. Recommended power levels are shown for tower climbing with or without the use of gloves. A study by Tell performed for the FCC (Reference 28 in Bulletin 65) indicated that certain gloves (particularly leather gloves) can significantly reduce the induction of RF currents in tower climbers.

Figure 5 is designed to be used to provide guidance for use by AM radio stations which find it necessary to continue transmitting while persons are climbing their towers. It can be used to determine the levels to which operating power should be reduced before a person climbs an active tower. However, there is variability in the data, and whenever there is a question about which condition may apply in a given situation it is recommended that the most conservative power level be used or, alternatively, that power be turned off completely while the climber is on the tower.

[2] See References 6, 26, 27, 28 and 32 in OET Bulletin 65.

TABLE 1. Predicted Distances for Compliance with FCC Limits: O.1 Wavelength

Frequency (kHz)	Transmitter Power (kW)			
	50	10	5	1
	Predicted Distance for Compliance with FCC Limits (meters)			
535-740	13	7	6	3
750-940	12	7	5	3
950-1140	11	6	5	3
1150-1340	10	6	5	3
1350-1540	10	6	5	3
1550-1705	10	6	5	3

TABLE 2. Predicted Distances for Compliance with FCC Limits: O.25 Wavelength

Frequency (kHz)	Transmitter Power (kW)			
	50	10	5	1
	Predicted Distance for Compliance with FCC Limits (meters)			
535-740	4	2	2	1
750-940	4	2	2	1
950-1140	4	2	2	1
1150-1340	4	2	2	1
1350-1540	4	2	2	1
1550-1705	5	2	2	1

TABLE 3. Predicted Distances for Compliance with FCC Limits: O.5 Wavelength

Frequency (kHz)	Transmitter Power (kW)			
	50	10	5	1
	Predicted Distance for Compliance with FCC Limits (meters)			
535-740	4	3	2	2
750-940	4	2	2	2
950-1140	4	2	2	1
1150-1340	4	2	2	2
1350-1540	4	2	2	2
1550-1705	4	3	2	1

TABLE 4. Predicted Distances for Compliance with FCC Limits: 0.625 Wavelength

Frequency (kHz)	Transmitter Power (kW)			
	50	10	5	1
	Predicted Distance for Compliance with FCC Limits (meters)			
535-740	4	3	2	1
750-940	4	2	2	1
950-1140	4	2	2	1
1150-1340	4	2	2	1
1350-1540	4	2	2	1
1550-1705	4	2	2	2

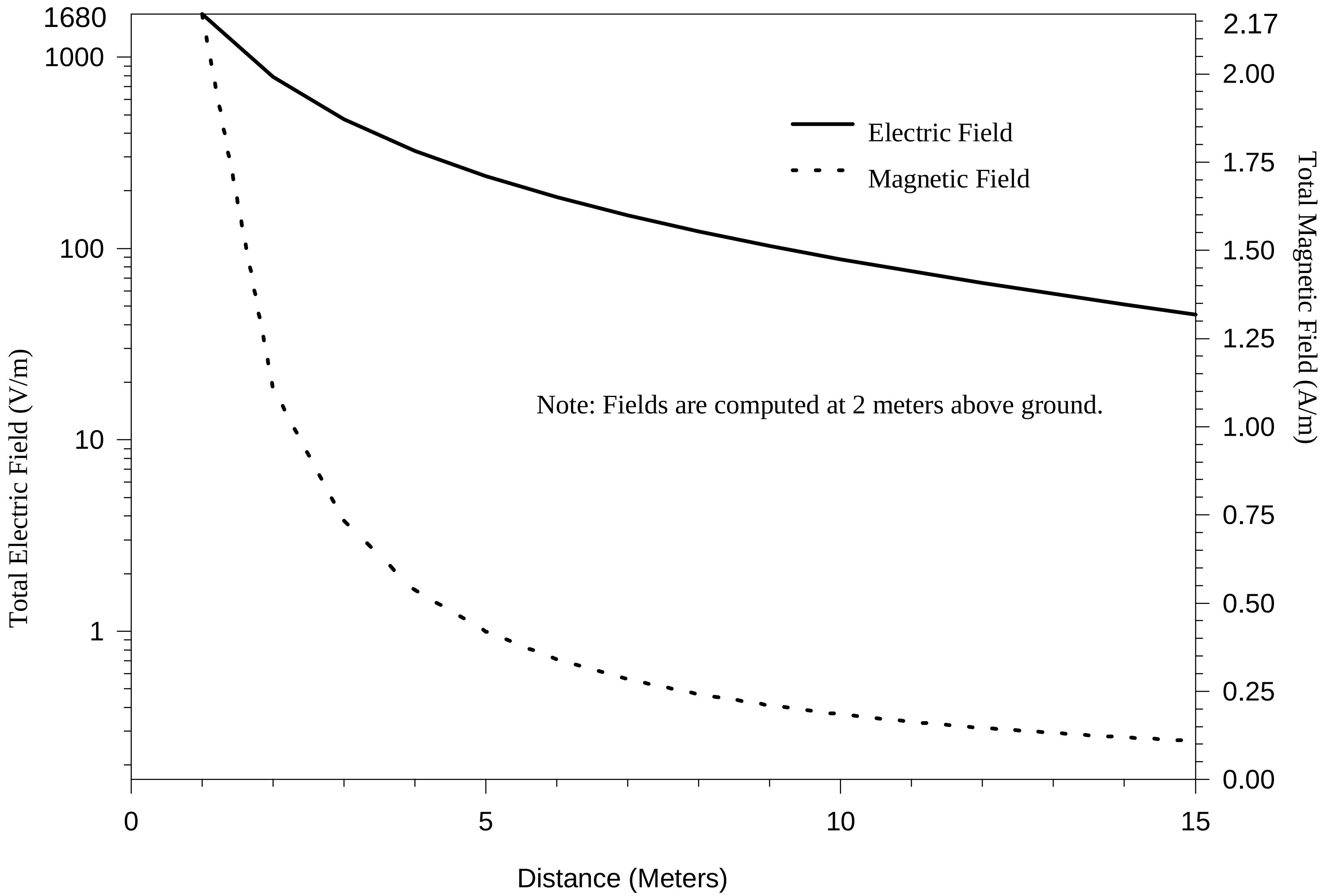

Figure 1. MININEC AM Model for 1 kW, 0.10 Wavelength Tower

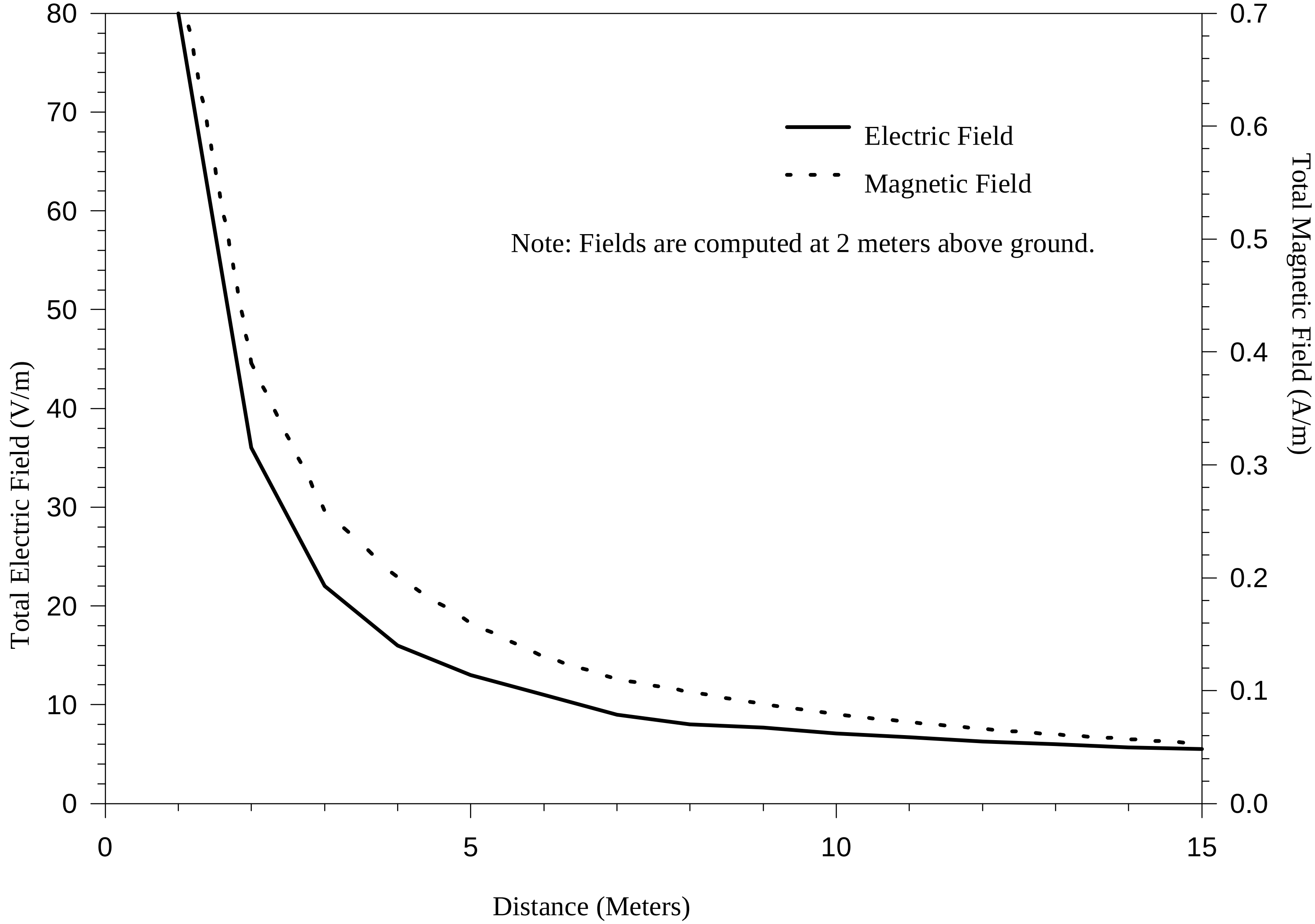

Figure 2. **MININEC AM Model for 1 kW, 0.25 Wavelength Tower**

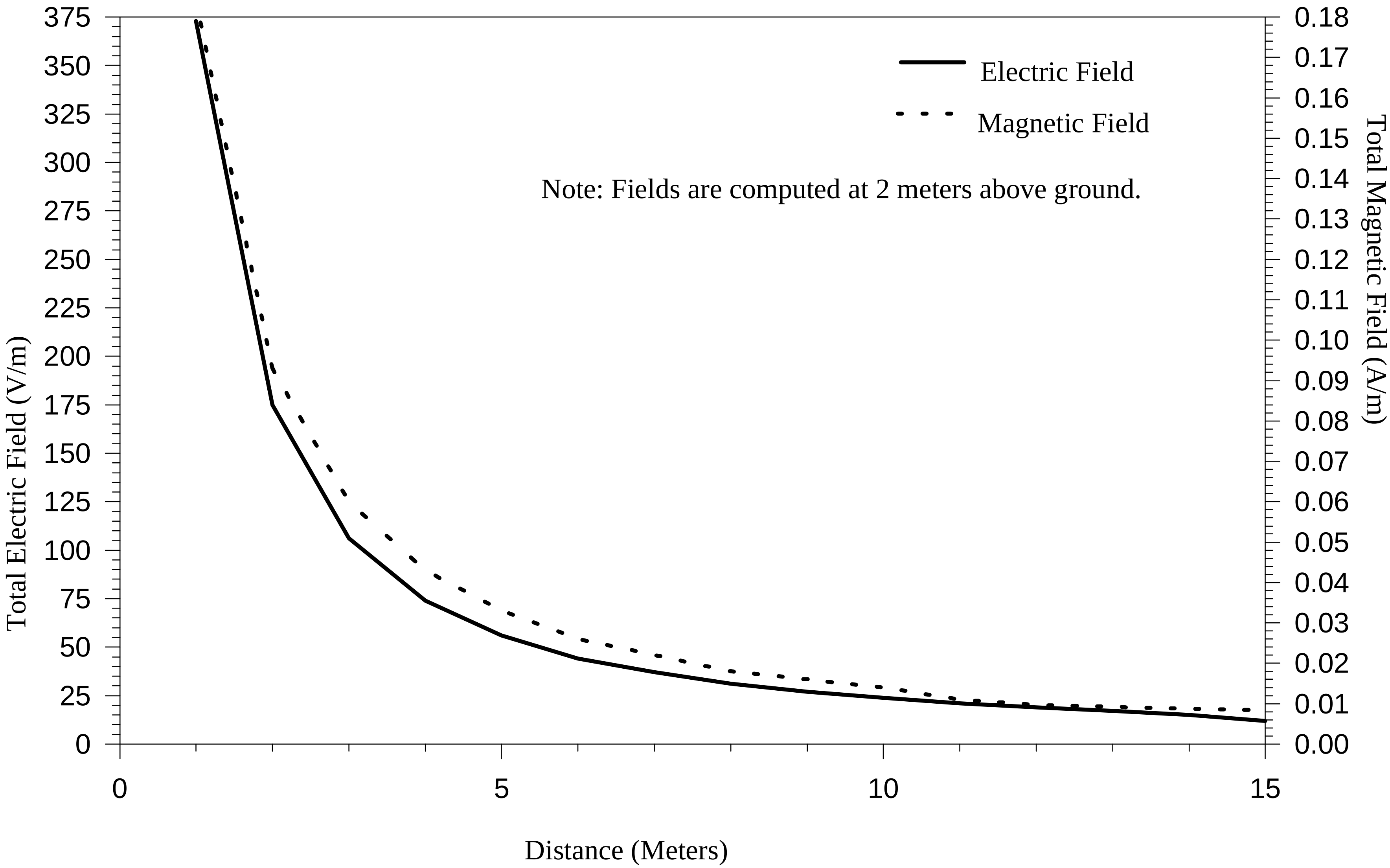

Figure 3. MININEC AM Model for 1 kW, 0.5 Wavelength Tower

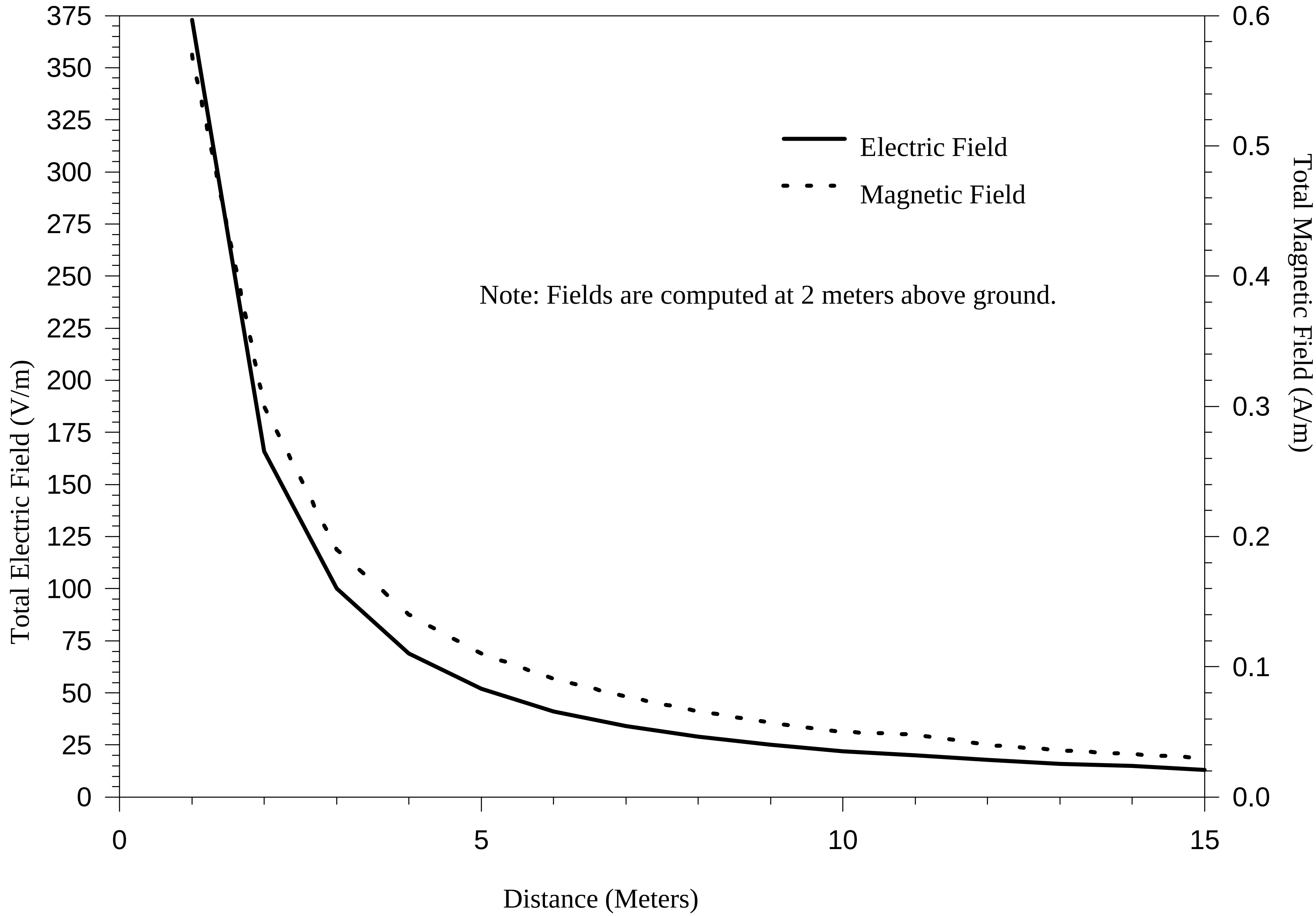

Figure 4. **MININEC AM Model for 1 kW, 0.625 Wavelength Tower**

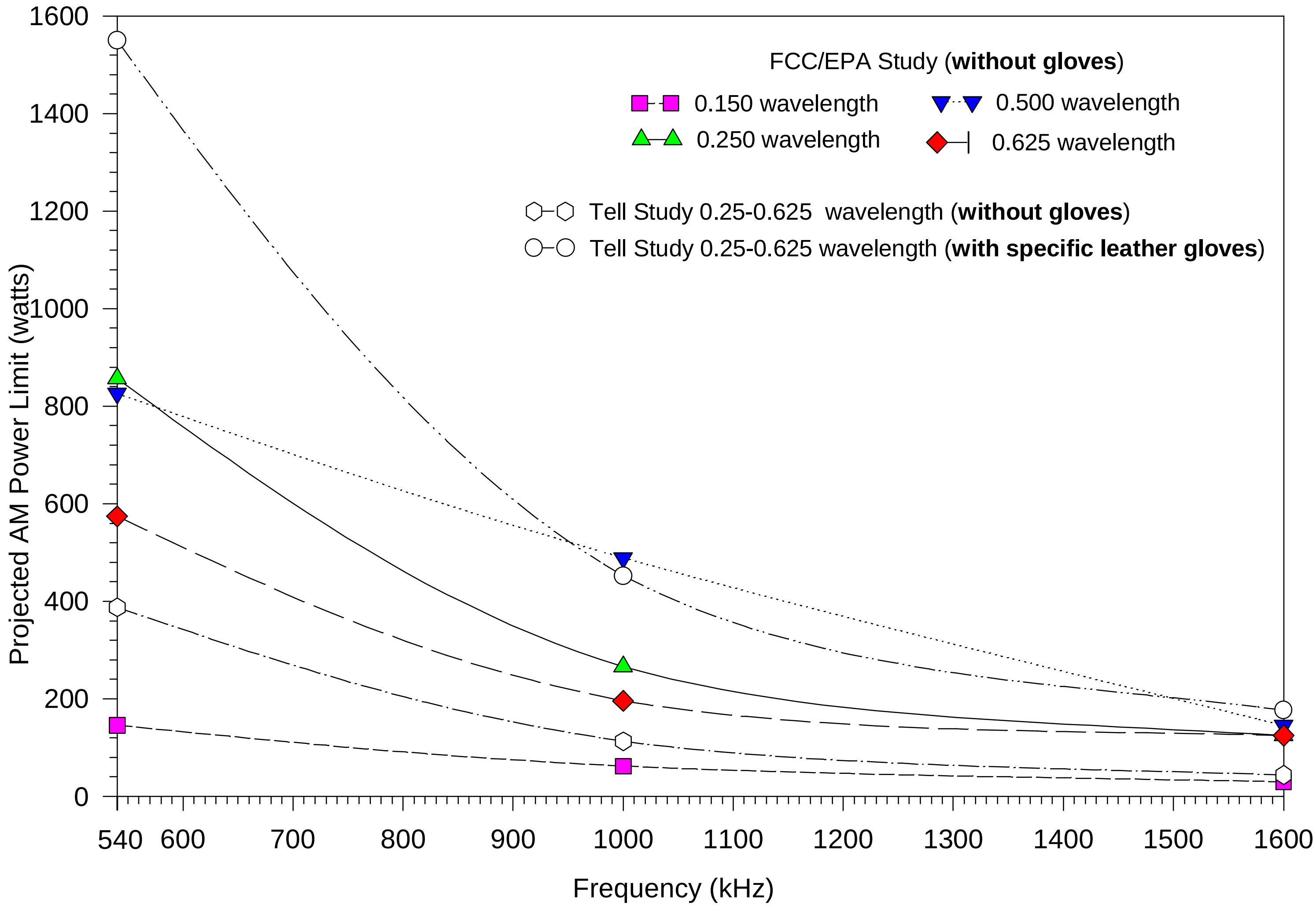

Figure 5. Estimated power levels to comply with occupational/controlled limits for ***on-tower*** exposure of persons climbing AM broadcast towers (applies ***only*** to exposure of persons climbing a transmitting AM radio tower).

SECTION 2
FM Radio Broadcast Stations

Antennas used for FM radio broadcast stations normally consist of an array of elements stacked vertically and typically side-mounted on a tower. The elements are usually spaced about one wavelength apart and are fed in phase with power distributed equally among the elements. FM radio stations transmit in the 88-108 MHz band. Consulting Table 1 in Appendix A of OET Bulletin 65 shows that at these frequencies the MPE limit for general population/uncontrolled exposure is 0.2 mW/cm^2 (200 $\mu W/cm^2$) and the limit for occupational/controlled exposure is 1 mW/cm^2 (1000 $\mu W/cm^2$).

Section 2 of Bulletin 65 explains how calculations can be performed to predict RF field-strength or power density near various antennas, including those used for FM radio transmissions. In addition, in 1985, the Environmental Protection Agency (EPA) developed a computer model for estimating ground-level power densities in the vicinity of typical FM broadcast towers. The EPA model estimates power densities in the vicinity of typical FM broadcast antennas for various antenna types and patterns. With some minor modifications, the FCC has successfully used this model over the past several years to predict ground-level power densities near FM towers. The EPA model considers the following variables of an FM antenna in arriving at is predictions: (1) the total effective radiated power (both horizontal and vertical), (2) the height above ground to the center of radiation of the antenna, (3) the type of antenna element used in the antenna array and (4) the number of elements (or bays) in the antenna array. The model is discussed in detail in an EPA publication by P. Gailey and R. Tell (Reference 11 in Bulletin 65). The FCC's version of the FM computer model can be downloaded from the FCC's Office of Engineering and Technology World Wide Web site.[3]

The FM computer model uses element and array radiation patterns to develop predicted field strengths and power densities on the ground.[4] Ground reflection is taken into account in these calculations (a factor of 1.6 for field strength as discussed in Section 2 of Bulletin 65). Although the model is theoretical, measurements made by the EPA and by others around existing FM antenna towers have shown good agreement with predicted values.

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[3] The FCC's FM computer model ("FM Model") may be downloaded via the Internet from the FCC's Web Site at http://www.fcc.gov/oet/info/software/. Any future revisions to this software may be found at this location. For further details contact: rf safety@fcc.gov or the FCC's RF Safety Program at (202) 418-2464.

[4] The EPA measured the vertical radiation patterns of several element types and incorporated the measurement data into its computer model. The FCC has also used the EPA element pattern data and has added other data submitted by manufacturers for additional antenna elements.

For a variety of antenna types, the FM computer model has been used by the FCC and others to predict values of far-field equivalent power density at specific locations on the ground relative to existing or proposed FM antennas. The model can also be used to predict the minimum height to an antenna's center of radiation necessary to prevent RF levels from exceeding an established level, such as the 200 $\mu W/cm^2$ MPE limit for general population/uncontrolled exposure. The FCC version of the FM computer model calculates fields at a height of 2 meters above ground, taken as the approximate upper range for the height of a standing person.

In performing any calculations for an FM radio antenna, whether using the equations of Section 2 of Bulletin 65 or by use of the FM computer model, the value used for ERP must be the ***total*** ERP. This means that in the case of a "circularly-polarized" antenna the sum of ***both*** the horizontal and vertical ERP values must be used. For example, an FM station using a circularly-polarized antenna that is authorized to use 100 kilowatts (kW) ERP in the horizontal polarization could be assumed to have a total ERP of 200 kW (100 + 100), unless otherwise specified.

Using the FM computer model, tables and figures have been derived for use by FM station licensees and applicants in evaluating compliance with the FCC's RF exposure limits. Table 5 lists estimated minimum antenna heights necessary to prevent power densities on the ground (actually at 2 m above ground) from exceeding the FCC's occupational/controlled MPE limits. Table 6 gives estimated antenna heights necessary to prevent "ground-level" power densities (2 m above ground) from exceeding the general population/uncontrolled MPE limits. The tables and figures in this section are designed to predict spatial peak values for power densities rather than values that are spatially-averaged over a given dimension such as the height of a human being. In that regard, the results may be conservative, and, in some cases, could indicate non-compliance when, in fact, a station may be in compliance.

Tables 5 and 6 should be consulted as a first step in evaluating an existing or proposed FM radio broadcast facility to determine whether it would comply with the FCC's MPE limits at ground level. Both tables will need to be consulted to ensure that ground-level exposures for all persons, whether workers or members of the general public, are below the appropriate acceptable levels. If non-compliance is indicated then some restriction of access or other mitigating measures may be necessary (see Section 4 of Bulletin 65 on controlling exposure for more information). In the case of Table 5, if a given tower height is less than the appropriate minimum value for occupational/controlled exposure, appropriate work practices may have to be implemented to ensure protection of personnel at the tower site (see Section 4 of Bulletin 65).

Note that Tables 5 and 6 give predicted minimum heights to the radiation center for a number of combinations of total ERP and number of elements (bays). Note that for each entry in the tables two values are given. In each case the top (higher) number represents the "worst case" where computations were based on using dipole elements in arrays with one-wavelength spacing.[5] The bottom (lower) entries in the table represent a typical "best case" where computations used antenna elements that, according to EPA's analysis, were designed to minimize radiation in the direction of the ground.[6]

It is important to recognize that the values in Tables 5 and 6 apply to ***single*** FM antennas and to towers whose bases are approximately at the same level or higher than the surrounding terrain. For multiple antennas on the same tower, it would be possible to arrive at a worst-case estimate using these tables by assuming that the total ERP from ***all*** antennas was concentrated at the radiation center of the antenna that is lowest on the tower. For such an imaginary radiating source, the number of elements could be considered to be that of the antenna with the smallest number of elements. A more accurate estimate could be made by using Figures 6-15 (described below) or by using the FM model software to estimate power density contributions from each antenna at a ground-level point of interest and then add the contributions to arrive at the total predicted power density at that point.

In some cases FM radio antennas may have a relatively large number of elements and the lowest element may be a significant distance from the radiation center. The FM computer model may not be accurate when predicting field levels from relatively large multiple-element arrays at distances very close to the antenna. For example, in some cases the minimum antenna height computed using the FM computer model may be on the order of or less than one-half the array length (meaning that the antenna would be mounted with its lowest element at or below ground). Obviously this is not a realistic or desirable situation. Therefore, in Tables 5 and 6, values have been adjusted to ensure that the lowest element in an array is at least 3 meters above ground-level ***in all cases,*** i.e., head height plus an additional 1-meter margin of safety. These adjusted numbers are marked with the "*" symbol.[7]

For FM antennas with ERP/element combinations that are intermediate to the values listed in Tables 5 and 6, interpolation can be used between table entries, assuming a direct relation between antenna height and power and an inverse relation between antenna height

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[5] As shown by the EPA model, the use of dipole elements in an array results in the greatest amount of downward radiation due to the approximately circular radiation pattern of a dipole.

[6] As shown by the EPA and others, other element types generate vertical radiation patterns that tend to minimize downward radiation significantly. The "best case" element studied by the EPA had a maximum downward radiation field factor of less than 0.2 compared to the approximate 1.0 maximum for a dipole element.

[7] These values were determined by first calculating the longest wavelength that can be utilized for FM radio broadcast (about 3.4 meters at 88 MHz). Assuming one-wavelength spacing between the elements in an antenna array, the greatest possible length for an array with a given number of elements can be approximated. Since the radiation center will be located in the middle of the array, the minimum height of the antenna above ground has to be at least one-half of the array length. The values for minimum height given in the tables are always at least 3 meters greater than one-half the calculated array length even though the FM computer model may indicate a lesser value.

and number of elements. Alternatively, the next highest value could be used for ERP and the next lowest value could be used for number of elements. For example, with respect to the public/uncontrolled MPE limits, an FM station with a total ERP of 20 kW and 5 elements could use the values given in Table 6 for 25 kW and 4 bays (51.5 meters, worst case, or 21.1 meters, best case), since these values would be conservative. Interpolation would yield more realistic values of either 45.4 m or 45.1 m for worst case, depending on whether the 4-bay or 6-bay column is used. Similar interpolation could be performed for the best case values.

In determining compliance for a proposed or existing FM facility, Tables 5 and 6 may be used initially to determine that a station is or will be in compliance with the MPE limits. However, if comparison with the appropriate values in the tables indicates potential non-compliance, i.e., if the antenna center of radiation is ***less*** than the indicated minimum tower height necessary for compliance, further analysis will be necessary. For example, Figures 6-15 can be consulted, calculations can be made (see Section 2 of Bulletin 65) or FM model software can be used to determine predicted field levels. Bulletin 65 can then be consulted for information on how to ensure compliance (e.g., Section 4 on controlling exposure).

Figures 6-15 were generated using the FCC's FM computer model. These figures include curves of predicted far-field equivalent, "ground-level" power density (2 m above ground) versus distance from the base of towers on which FM antennas are mounted for various combinations of total ERP, height to radiation center and number of elements. By consulting the appropriate figure, the exposure level at a given point near the ground can be predicted, thereby determining places where access may have to be restricted. It should be emphasized that these figures show ***"worst-case"*** curves assuming dipole elements in the FM antenna array. Therefore, the values in these figures should be conservative and should represent the upper range for power densities for the given conditions. In general, if the FM computer model is used with other element type different curves, with lower power density values, would be generated for a given set of conditions.

The following example illustrates how Figures 6-15 could be used to identify the area around the base of an FM broadcast tower where access may have to be restricted or power densities may have to be reduced in some way in order to comply with the MPE limits. In this example it is desired to determine the location where the MPE limit for general population/uncontrolled exposure of 200 µW/cm^2 for the FM radio band would be predicted to be exceeded. Assume that the station has the following characteristics:

- Total ERP = 200 kW (100 kW horizontal + 100 kW vertical polarization)
- Height above ground to radiation center = 82 meters
- Number of elements = 4
- Spacing between elements in the antenna array = 1.0

The height of the radiation center in this example is 82 meters, which can be rounded to 80 meters for purposes of using the appropriate figure (Figure 13). It is necessary to round down instead of up so that the power density will not be underestimated. Figures 6-15 are normalized for 1 kW of total ERP, i.e., power density values are in terms of power density per kilowatt ERP, so the power density values given in the figure will have to be converted to account for the higher power level of the example station. The following procedure should be used to obtain the desired information.

- ✓ Divide the MPE limit of 200 µW/cm^2 by the total station ERP of 200 kW to obtain 1 µW/cm^2/kW (power density per kW)
- ✓ Find 1 µW/cm^2/kW on the vertical axis of Figure 13 (for 80 m antenna height)
- ✓ Find the point on the 4-element curve corresponding to 1 µW/cm^2/kW and locate the predicted distance (about 48 m) on the horizontal axis

The result of this analysis means that a fence or other appropriate restrictive barrier could be placed at this distance to prevent access to the tower site where levels are predicted to exceed the MPE limits for the general public. This would be a means to comply with the general population/uncontrolled MPE limits. Section 4 of Bulletin 65 provides further discussion on controlling exposure.

Figures 6-15 can be used to predict exposure to any power density level by using the above-described approach. For example, to find the minimum distance to 1000 µW/cm^2 (the occupational/controlled exposure limit for the FM band), simply divide 1000 (rather than 200 in the above example) by the total ERP and proceed as above. In that case, the resulting value of 5 µW/cm^2/kW would imply that the 1000 µW/cm^2 limit would ***not*** be exceeded anywhere near the ground for these conditions, since all the numerical values on the curve lie below this threshold.

It is important to re-emphasize that the predicted values shown in Figures 6 - 15 are ***worst case*** estimates (dipole elements) that represent the ***maximum*** predicted levels possible for any FM antenna using conventional element arrays. Therefore, they are primarily useful as a conservative approximation that may serve to eliminate the need for further analysis in many cases. It is very likely that use of most modern, commercially-available FM antennas will result in actual ground-level power densities that are significantly lower than the values shown by the curves in these figures. More accurate predictions can be made for these antennas by using the FM computer model and specifying an element type appropriate to the antenna system used.

For instances in which an FM antenna is mounted on a building or when the exposure location being analyzed is not on the ground, Tables 5 and 6 may not apply. For example, to determine exposure in or on a nearby building or other structure that may be in the direct line-of-sight of an FM antenna, field strength or power density in the ***main-beam*** of the antenna is more relevant for analytical purposes, and Figures 1 and 2 in Section 2 of Bulletin 65 should be consulted. However, if the location of concern is the rooftop itself, where an antenna is mounted above the rooftop, then the minimum antenna heights in Tables 5 and 6 could be used as if the rooftop represented the ground.

Total H+V ERP (kW)	Number of Bays					
	2	4	6	8	10	12
	Meters from Center of Radiation					
0.5	5.2 4.7*	8.1* 8.1*	11.5* 11.5*	14.9* 14.9*	18.3* 18.3*	21.7* 21.7*
3	9.7 5.7	9.7 8.1*	11.5* 11.5*	14.9* 14.9*	18.3* 18.3*	21.7* 21.7*
10	16.2 8.6	16.0 8.1*	15.9 11.5*	15.8 14.9*	18.3* 18.3*	21.7* 21.7*
25	24.3 12.5	24.2 9.8	24.0 11.5*	23.7 14.9*	23.5 18.3*	23.3 21.7*
50	33.6 16.8	33.3 13.1	33.1 11.3	32.7 14.9*	32.4 18.3*	32.1 21.7*
75	40.7 20.1	40.3 15.6	40 13.3	39.6 14.9*	39.2 18.3*	38.9 21.7*
100	46.6 22.9	46.3 17.7	45.9 15.1	45.4 13.7	45.0 18.3*	44.6 21.7*
125	51.9 25.4	51.5 19.6	51.1 16.6	50.6 15.1	50.0 18.3*	49.6 21.7*
150	56.7 27.6	56.2 21.2	55.8 18.0	55.2 16.4	54.6 18.3*	54.1 21.7*
175	61.1 29.7	60.5 22.7	60.1 19.3	59.5 17.5	58.8 16.3	58.3 21.7*
200	65.1 31.6	64.6 24.2	64.1 20.5	63.4 18.6	62.7 17.2	62.2 21.7*

Table 5 . Minimum height for single FM antenna compliance with occupational/controlled exposure limits. The above numbers apply to single FM antennas for which the base of the supporting tower is at approximately the same level or higher than the surrounding terrain. For each entry, the higher number represents a "worst case" assuming a dipole-type element in the antenna array. The lower number for each entry represents a typical "best case" achievable using modern, commercially-available antennas. For intermediate combinations of power or number of elements interpolation is acceptable, as explained in the text. See text for explanation of entries with "*" symbol.

Total H+V ERP (kW)	Number of Bays					
	2	4	6	8	10	12
	Meters from Center of Radiation					
0.5	9.1 5.3	9.0 8.1*	11.5* 11.5*	14.9* 14.9*	18.3* 18.3*	21.7* 21.7*
3	19.3 10.1	19.2 8.1	19.0 11.5*	18.8 14.9*	18.7 18.3*	21.7* 21.7*
10	33.6 16.8	33.3 13.1	33.1 11.3	32.7 14.9*	32.4 18.3*	32.1 21.7*
25	51.9 25.4	51.5 19.6	51.1 16.6	50.6 15.1	50.0 18.3*	49.6 21.7*
50	72.6 35.1	71.9 26.8	71.4 22.7	70.7 20.6	69.9 19.1	69.3 17.6
75	88.4 42.6	87.7 32.5	87.0 27.3	86.1 24.8	85.1 22.9	84.4 21.2
100	101.8 48.8	100.9 37.1	100.1 31.2	99.1 28.3	98.0 26.2	97.1 24.1
125	113.6 54.6	112.6 41.2	111.7 34.6	110.5 31.4	109.3 29.0	108.4 26.7
150	124.2 59.6	123.1 45.0	122.2 37.9	120.9 34.2	119.6 31.6	118.5 29.1
175	133.4 64.0	132.8 48.3	131.8 40.6	130.4 36.7	129.0 33.9	127.9 31.2
200	143.1 68.0	141.8 51.7	140.8 43.3	139.3 39.1	137.7 36.1	136.5 33.2

Table 6. Minimum height for single FM antenna compliance with general population/uncontrolled exposure limits. The above numbers apply to single FM antennas for which the base of the supporting tower is at approximately the same level or higher than the surrounding terrain. For each entry, the higher number represents a "worst case" assuming a dipole-type element in the antenna array. The lower number for each entry represents a typical "best case" achievable using modern, commercially-available antennas. For intermediate combinations of power or number of elements interpolation is acceptable, as explained in the text. See text for explanation of entries with "*" symbol.

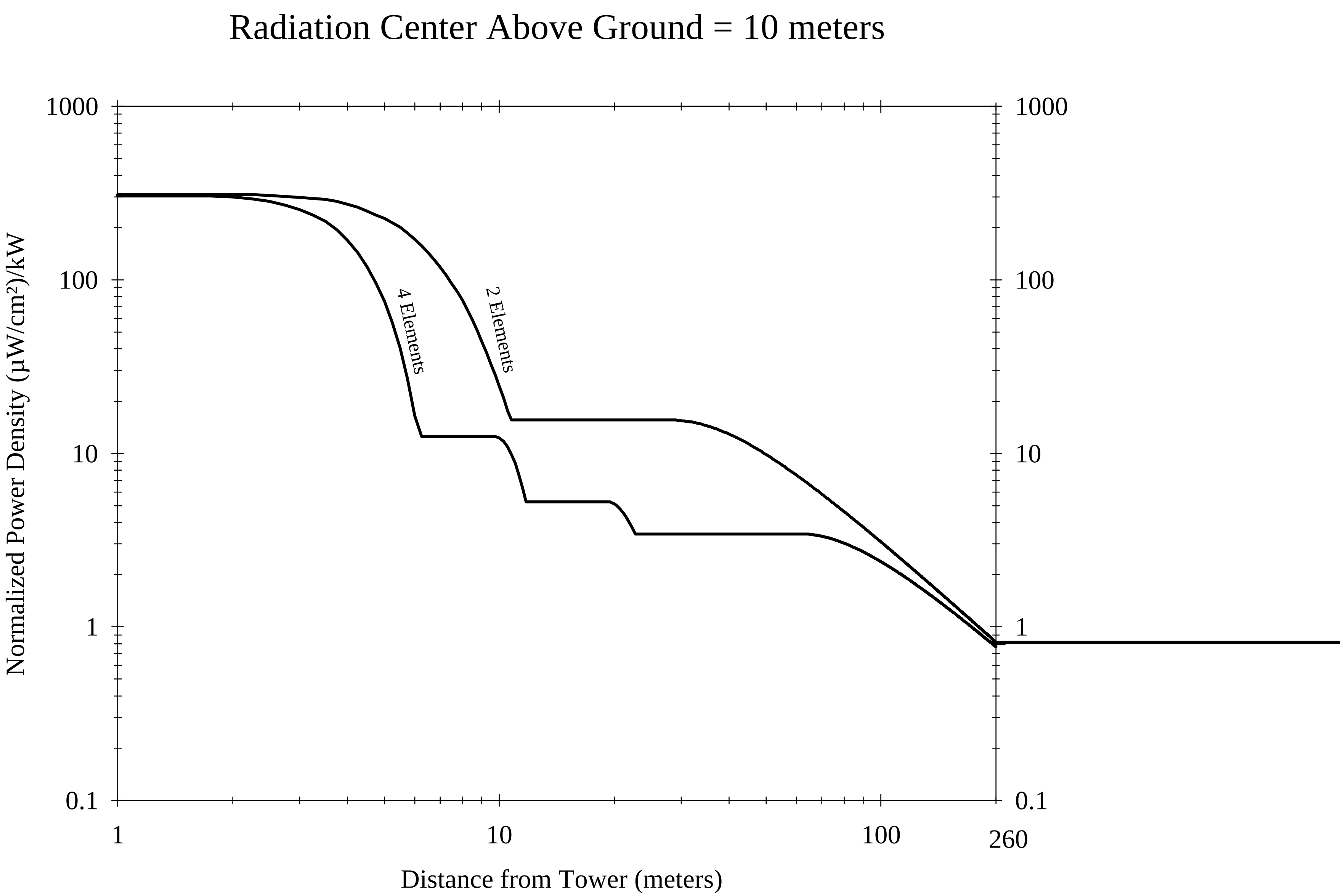

Figure 6. Predicted "worst case" power density (@ 2 m above ground) for 10 m antenna height.

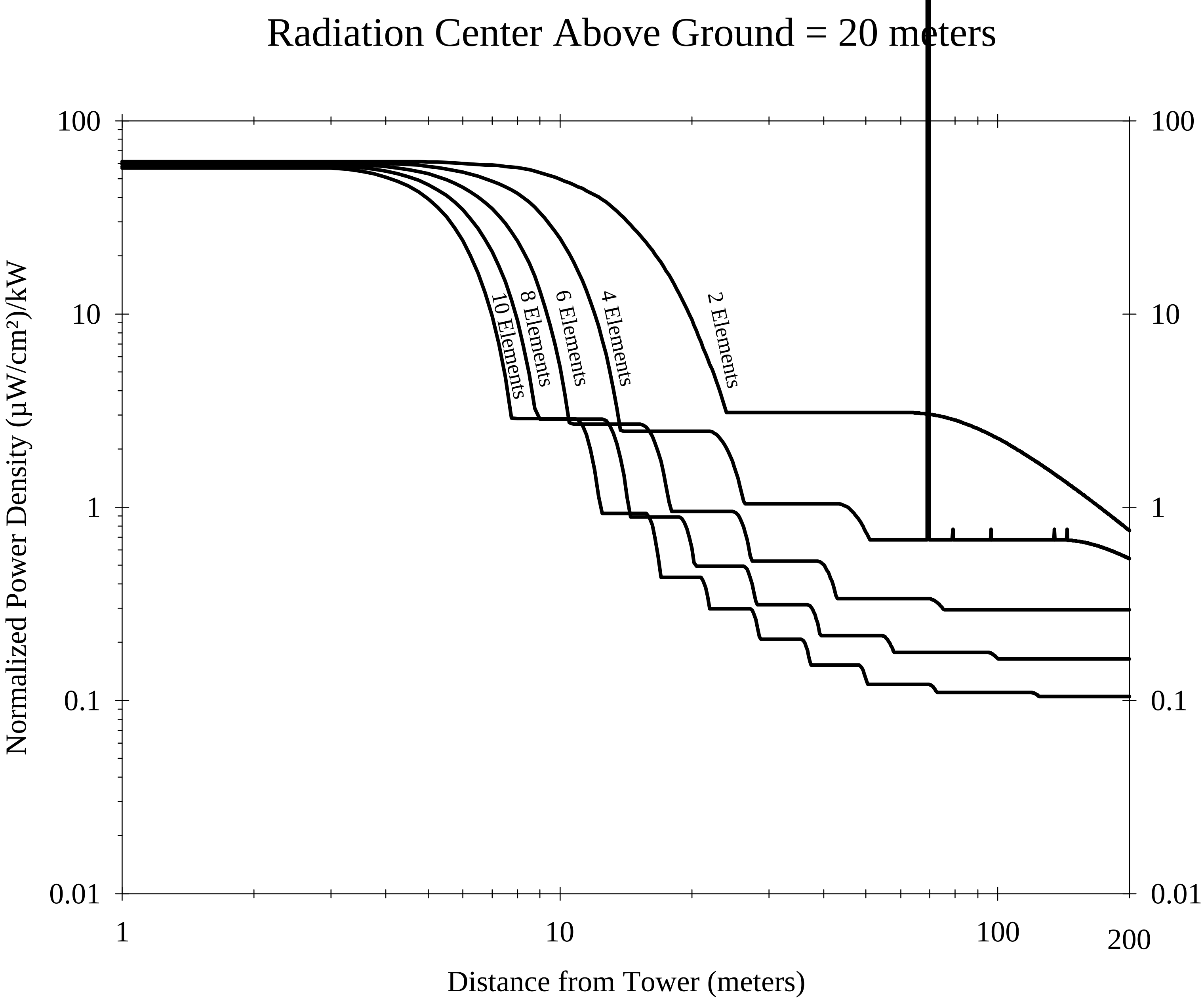

Figure 7. Predicted "worst case" power density (@ 2 m above ground) for 20 m antenna height.

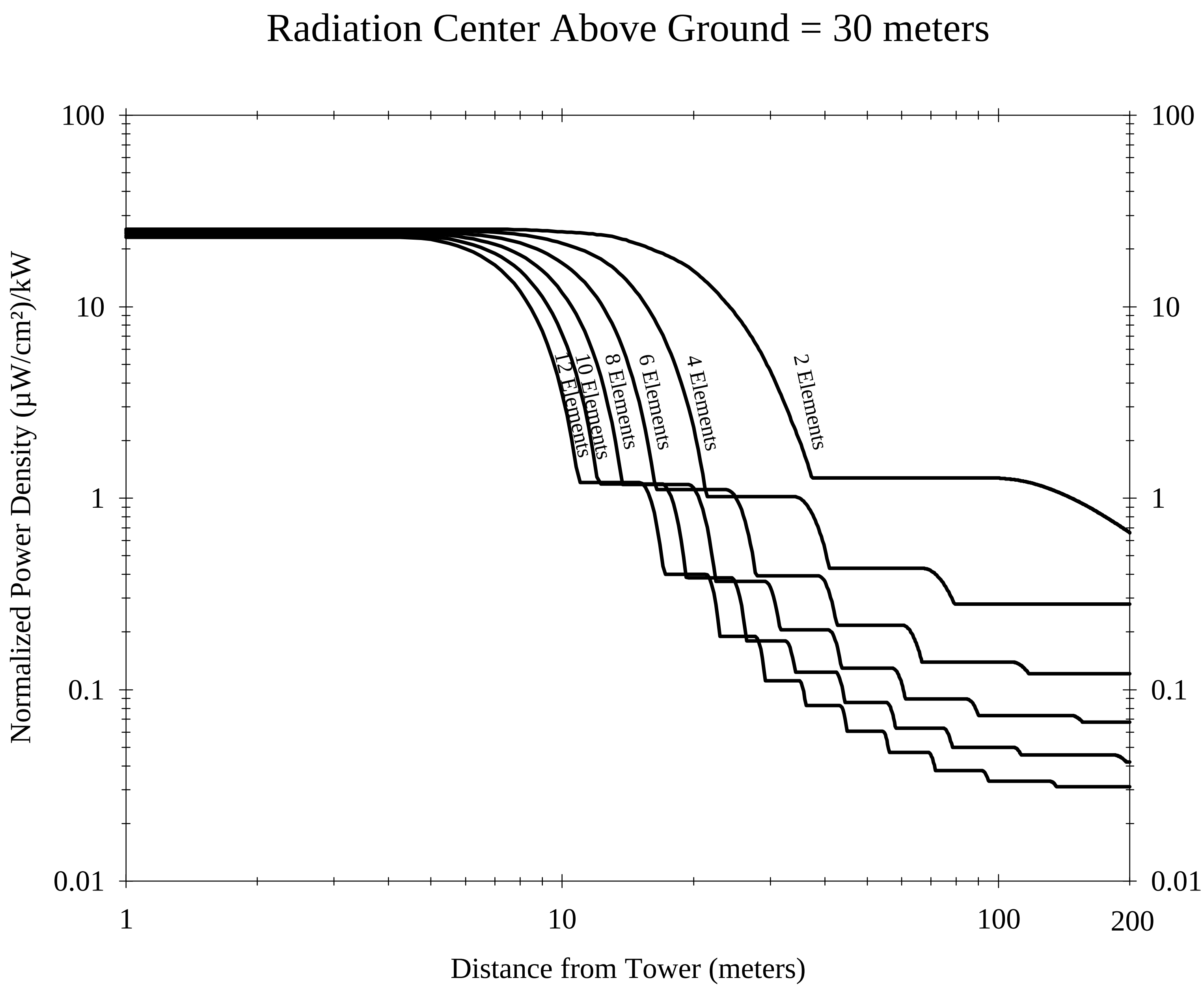

Figure 8. Predicted "worst case" power density (@ 2 m above ground) for 30 m antenna height.

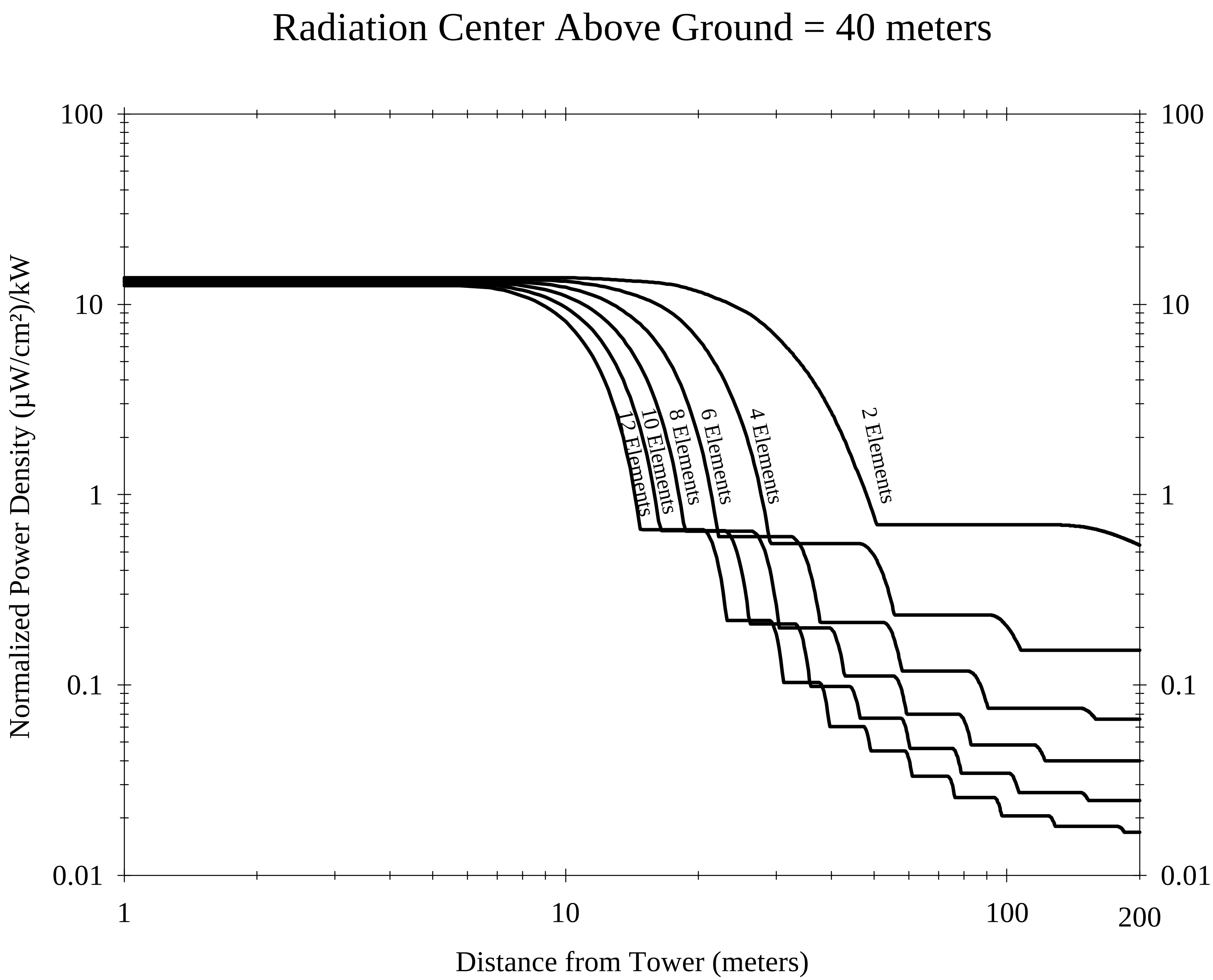

Figure 9. Predicted "worst case" power density (@ 2 m above ground) for 40 m antenna height.

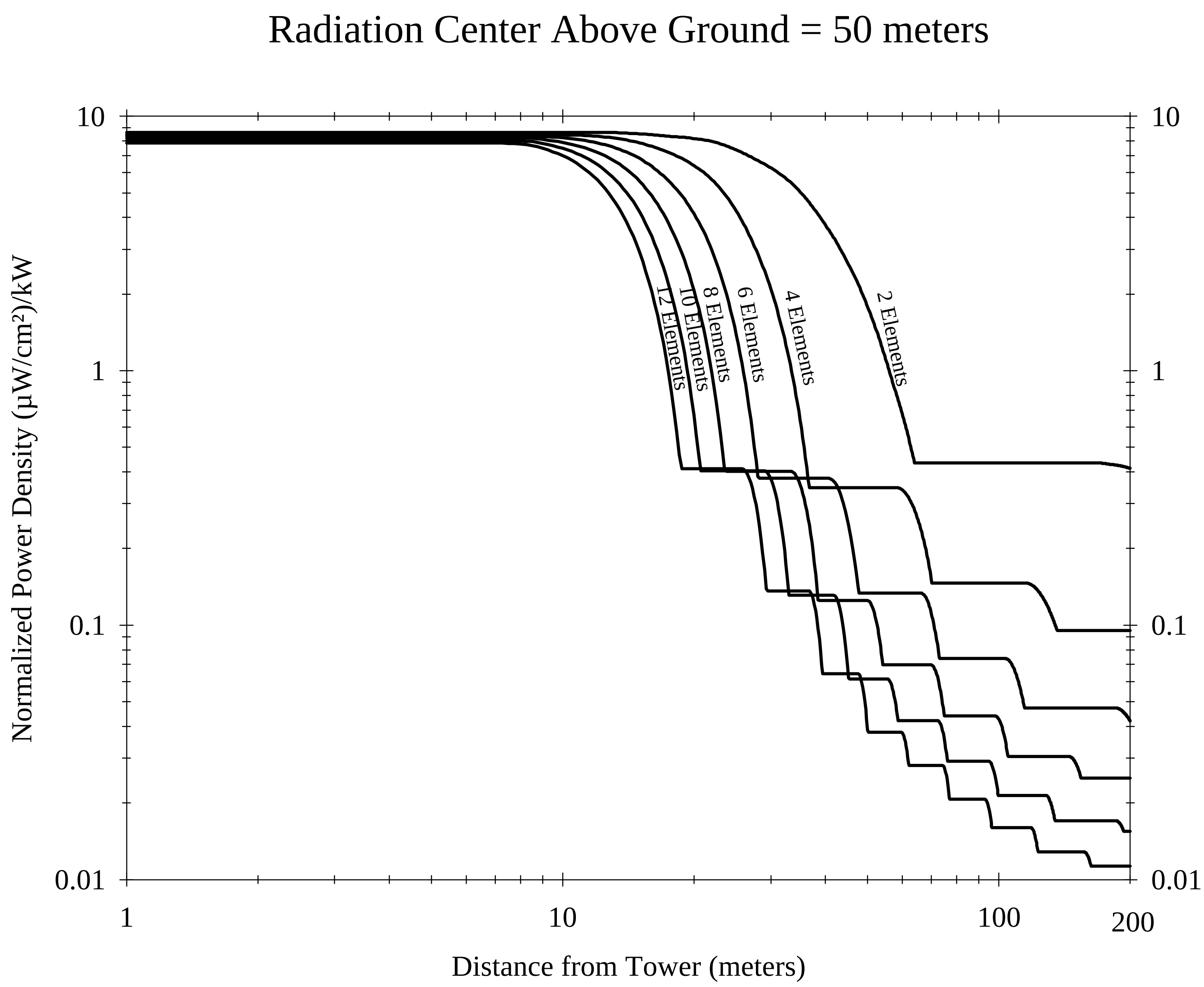

Figure 10. Predicted "worst case" power density (@ 2 m above ground) for 50 m antenna height.

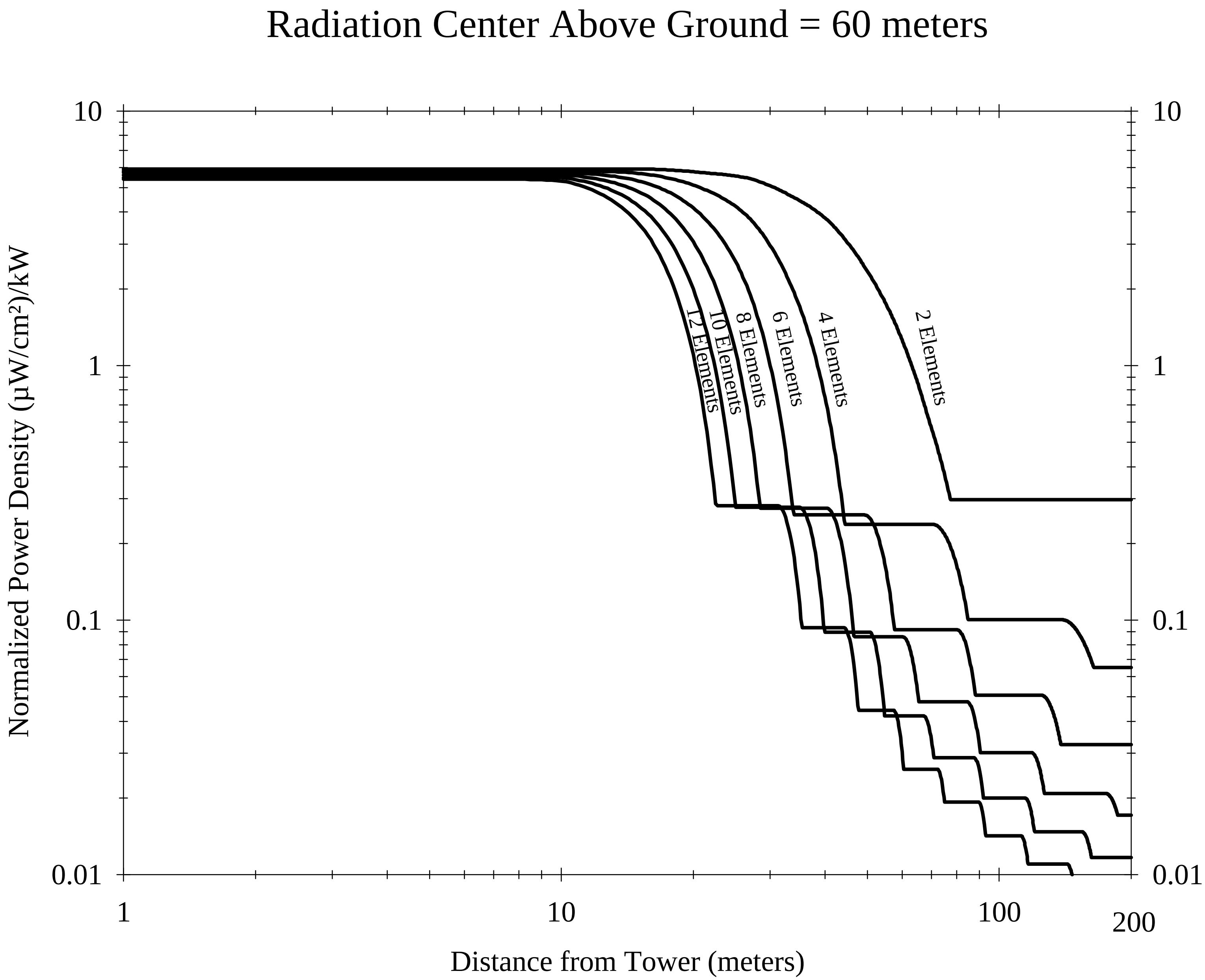

Figure 11. Predicted "worst case" power density (@ 2 m above ground) for 60 m antenna height.

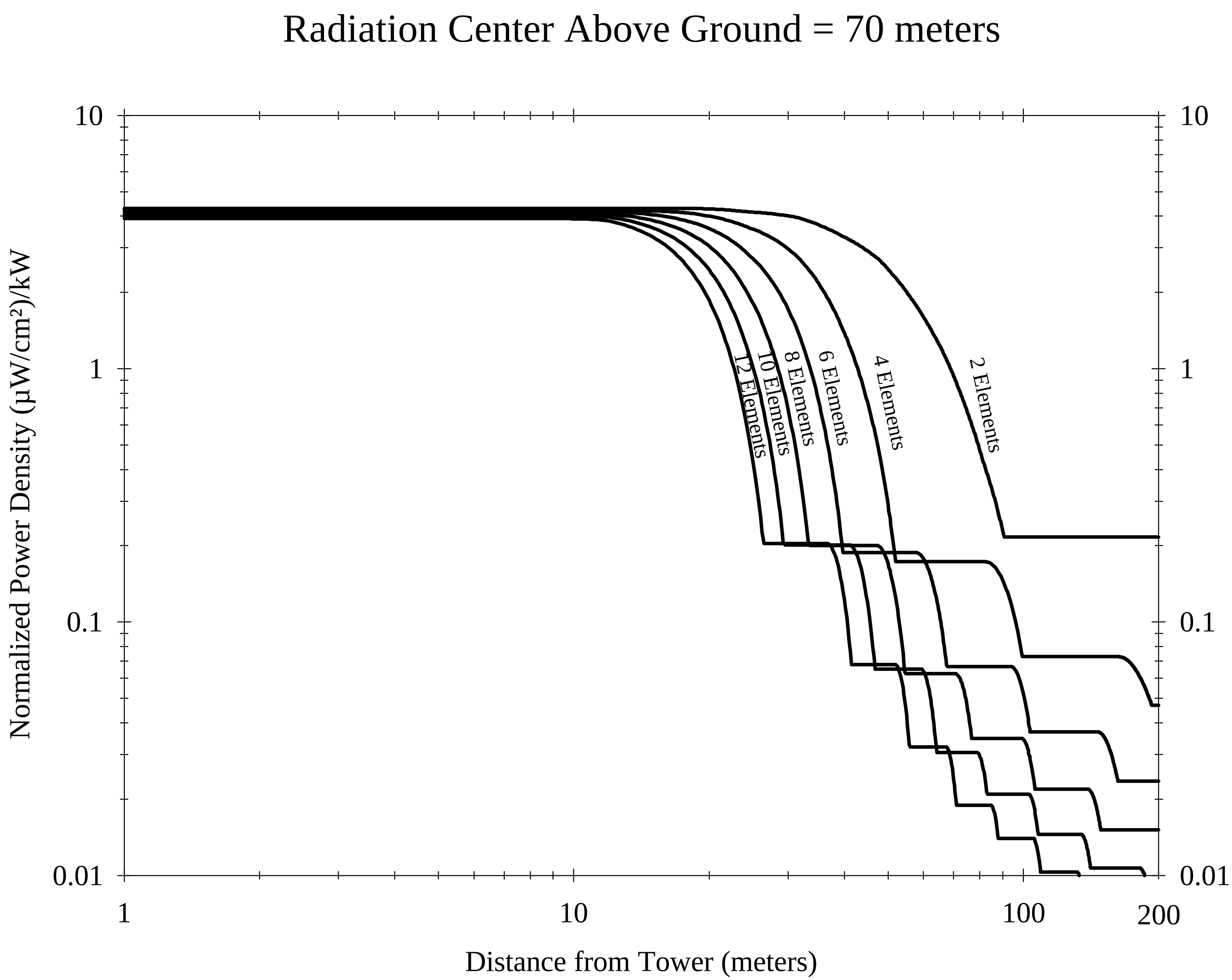

Figure 12. Predicted "worst case" power density (@ 2 m above ground) for 70 m antenna height.

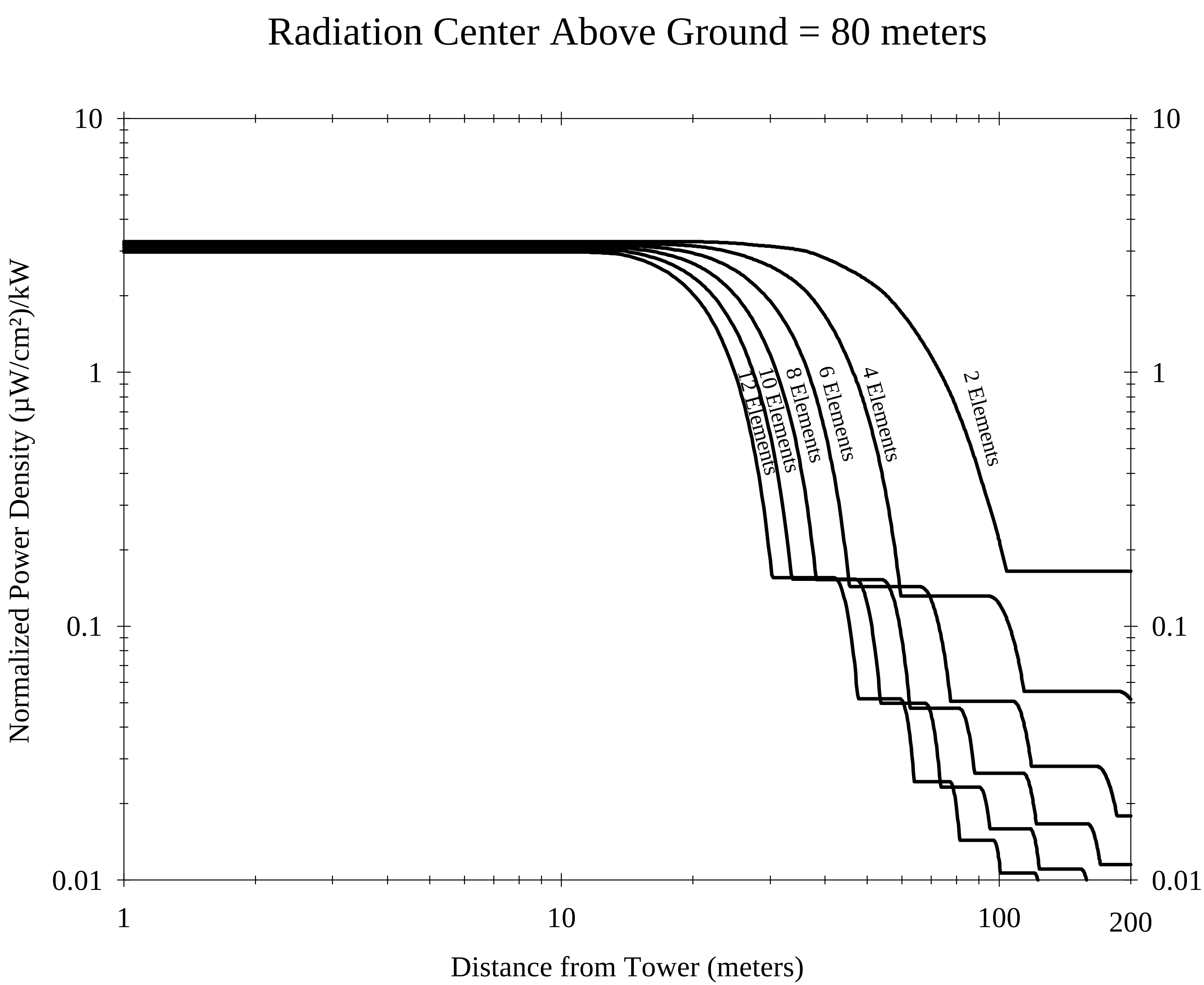

Figure 13. Predicted "worst case" power density (@ 2 m above ground) for 80 m antenna height.

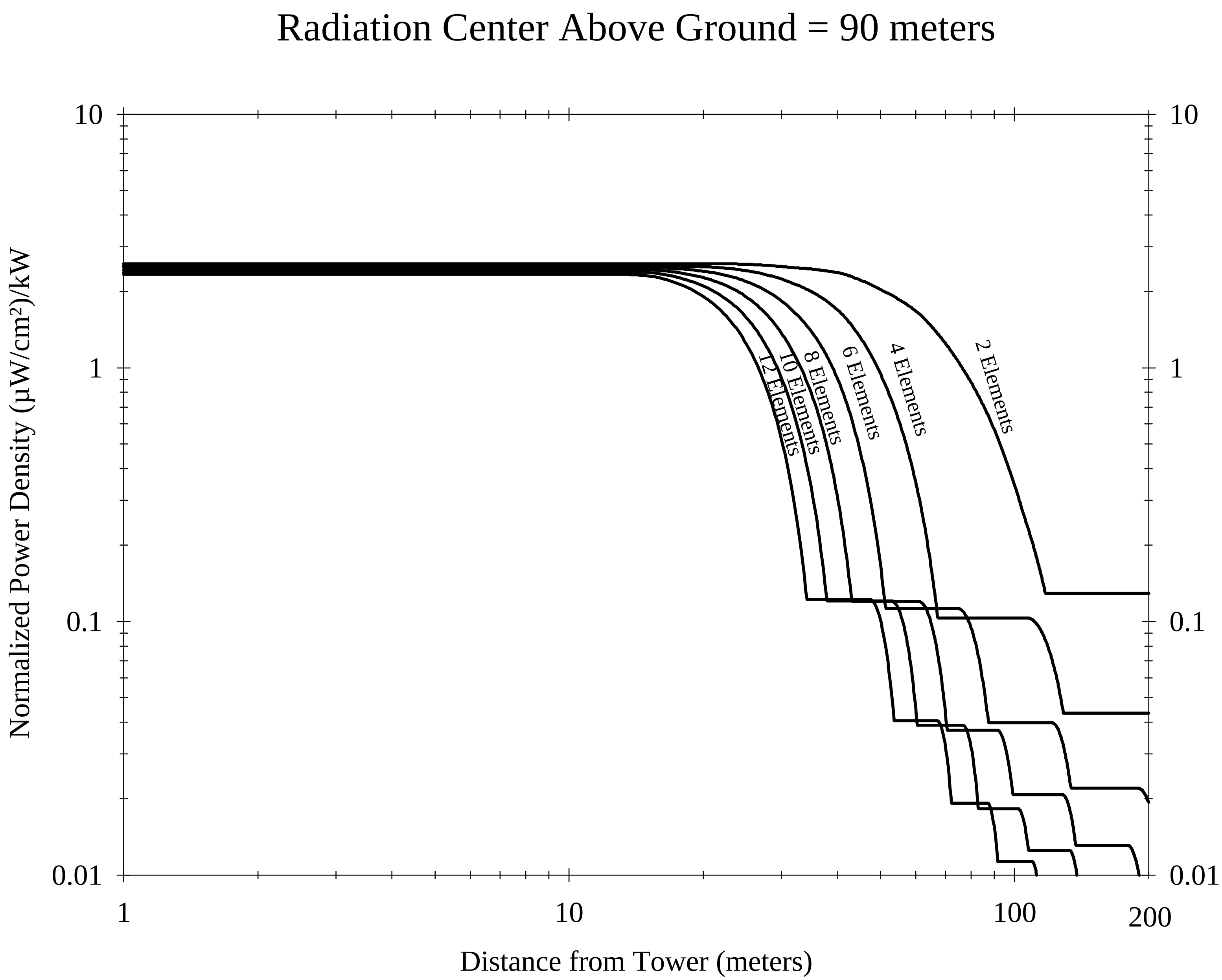

Figure 14. Predicted "worst case" power density (@ 2 m above ground) for 90 m antenna height.

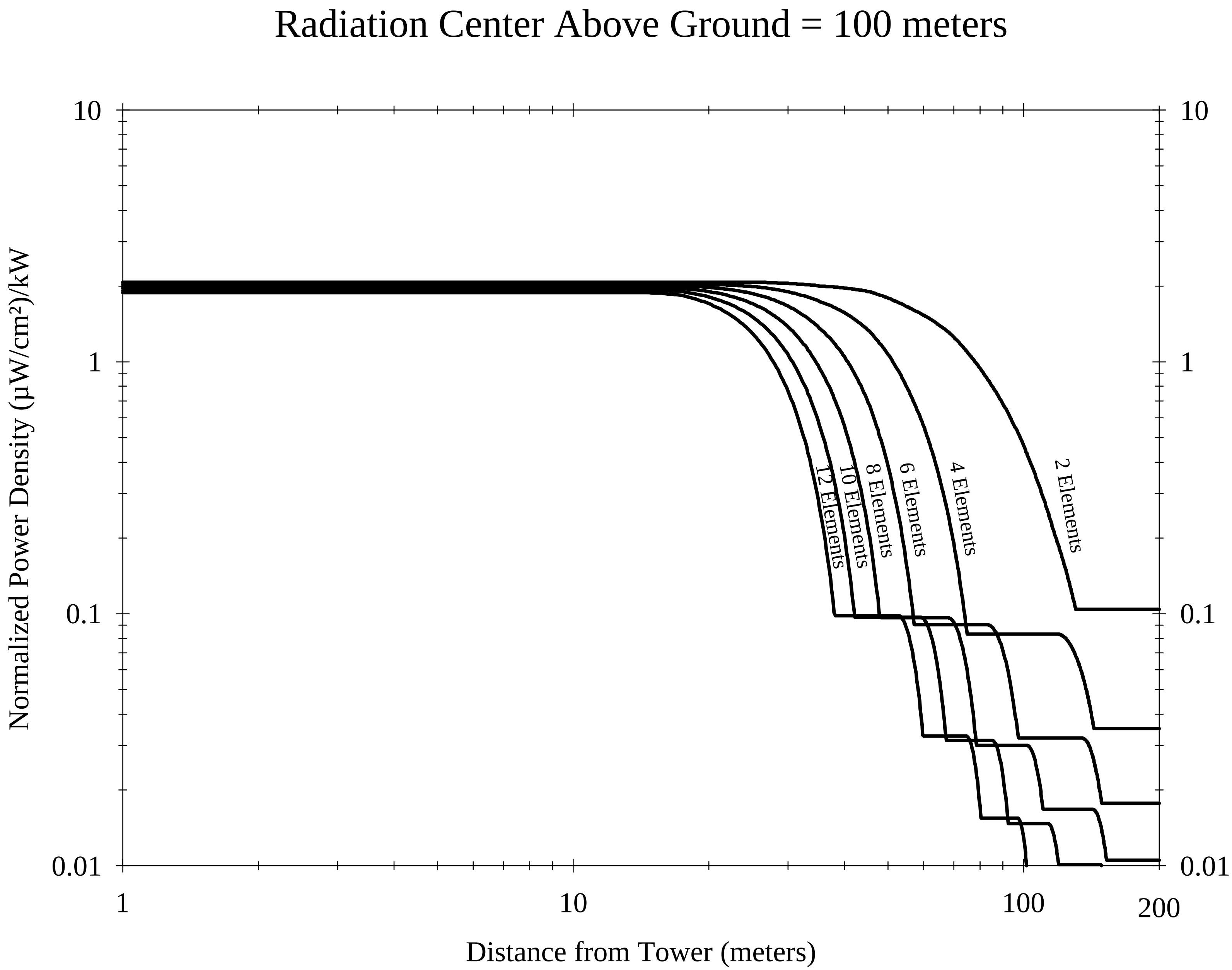

Figure 15. Predicted "worst case" power density (@ 2 m above ground) for 100 m antenna height.

SECTION 3
Television Broadcast Stations

Antennas used for television broadcasting usually consist of an array of radiating elements mounted on a tower. In comparison to elements used for FM antennas, the elements used for television broadcasting are generally of a more complex design and radiate less energy downward than many FM antennas. Television broadcast antennas are also often mounted on higher towers than those used for FM radio broadcasting.

The computer model developed by the EPA for FM radio broadcast antennas, discussed previously, was not applied to television broadcast antennas due to the unavailability of complete vertical radiation patterns for these antennas. However, the EPA did develop an alternative approach for analyzing television antenna systems based on available information. It should be noted that this model will have to be modified in the future if it is to be applied to digital television systems expected to be developed over the next several years.

For VHF-TV antennas, the EPA reported that the most commonly used type of radiating element appeared to be the "bat wing" type. For purposes of preliminary evaluation it can be assumed that all VHF-TV elements are of this design. Data obtained by EPA indicated that antennas using batwing elements may radiate approximately 20% as much in the downward direction as in the main beam in terms of relative field strength. Therefore, the relative field factor, F (discussed in Section 2 of Bulletin 65), in the downward direction could be assumed to be on the order of 0.2.[8]

Although detailed modeling was not performed, the EPA used typical values of relative field strength directly beneath the antenna, i.e., the shortest distance to ground, to arrive at its prediction model for ground-level fields due to VHF-TV antenna systems. For directions other than straight down, greater distances from the antenna would be involved,

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[8] The use of a relative field factor (F) allows a more accurate prediction for power density. If the relative field factor is not known, a value of 1.0 could be assumed for a ***very conservative,*** worst-case approximation. The 20% level assumed by EPA for VHF-TV antennas in the downward direction is an average value and would not necessarily apply in all cases. However, a value of 1.0 in the downward direction is unlikely for TV antennas. A 1.0 value for the field factor is more appropriate for evaluating main-beam exposure.

resulting in lower predicted fields at ground level. The EPA developed the following general equation to predict fields at the base of television broadcast towers.

$$S = \frac{(2.56)(1.64)(100)\ (F^2)\ [0.4ERP_V + ERP_A]}{4\pi R^2} \qquad (1)$$

where:

S = power density in microwatts/sq. cm ($\mu W/cm^2$)
F = relative field factor in the downward direction of interest (-60° to -90° elevation)
ERP_V = total peak visual ERP in watts[9]
ERP_A = total aural ERP in watts
R = distance from ground (or @ 2m above ground) to center of radiation in meters

In Equation (1) the value of 2.56 is the ground-reflection factor discussed in Section 2 of Bulletin 65. The value of 1.64 is the gain of a half-wave dipole relative to an isotropic radiator, also as discussed in Section 2. The factor of 0.4 converts peak visual ERP to an RMS value which is more realistic with regard to practical conditions of video transmission. The factor of 100 in the equation is a conversion factor. For convenience Equation (1) can be simplified to the following expression (same units as above):

$$S = \frac{33.4\ (F^2)\ [0.4ERP_V + ERP_A]}{R^2} \qquad (2)$$

If the relative field factors, F, (derived from the relative power gain) are known from an antenna's vertical radiation pattern, Equations (1) and (2) can be used to arrive at predictions of ground-level power density that are much more accurate than would be the case by using a worst-case estimate of 1.0 for F. For VHF-TV antennas the value of 0.2 for F can generally be assumed. However, it should be kept in mind that this value generally represents an average and may not necessarily apply in all cases and in all directions.

The following equation, Equation (3), derived from Equations (1) and (2) can be used to predict the minimum antenna height necessary to bring a television station below a given power density level anywhere on the ground:

[9] The values for ERP in this equation are ***tota***l ERP. Therefore, although most television antennas transmit in the horizontal polarization, if a circularly-polarized antenna should be used the contributions from both horizontal and vertical polarizations must be included.

$$MAH = \sqrt{\frac{33.4\ (F^2)\ \ [0.4\ ERP_V + ERP_A]}{S}} \qquad (3)$$

where: MAH = minimum antenna height (ground to center of radiation) necessary to reduce ground-level RF fields below a given power density, S, (units same as Equation 1).

Equations (1) - (3) can be used for both VHF and UHF television antennas. However, for UHF antennas, the EPA model used different typical values of F, the relative field factor in the downward direction. It is reasonable to expect generally smaller F values for UHF antennas than from VHF antennas. UHF antennas have very high gain in the main beam which means that a higher proportion of the transmitted energy is concentrated there rather than radiated downward or in other directions. Although EPA was not able to obtain relative field data from antenna manufacturers' literature, an alternative prediction method was developed based on field data and discussions with one major manufacturer. The manufacturer's engineers stated that typical values of F for UHF antennas are about 10%, and some more expensive antennas have an F of about 5% for downward radiation. These values agreed well with measurements made by the EPA in field studies beneath UHF antennas.

Equation (3) was used to prepare Tables 7 - 12 in this section. These tables show minimum "worst case" distances from single VHF or UHF television antennas required for compliance with the FCC's MPE limits.[10] Individual tables specify various combinations of visual and aural power and show distances for compliance with either general population/uncontrolled limits or occupational/controlled limits, with or without the assumption of surface reflection.[11] For intermediate values of visual or aural power an applicant may interpolate between values given in the tables, or, alternatively, use the value given for the next highest level of visual and/or aural power. As indicated previously, ***total*** ERP must be used.

When F, the relative field factor, is known, Equation (3) above can be used to calculate minimum antenna height for compliance with a specified limit. However, if F is not known, the values given in these tables can be used (which assume a value of 1.0 for F) as a worst-case estimate for ground-level exposure. However, these values will be very

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[10] Note that for VHF-TV frequencies the MPE limits are 200 µW/cm^2 (general population/uncontrolled) and 1000 µW/cm^2 (occupational/controlled). For UHF-TV frequencies the MPE limits vary with frequency (see Appendix A to Bulletin 65 for details).

[11] Surface reflection will result in higher predicted values (see Section 2 of Bulletin 65).

conservative, as discussed previously. Tables using field factors less than 1.0, such as 0.2 or 0.1, could also be constructed and may be included in future revisions of this supplement.

Using Tables 7 - 12 for estimating minimum antenna height can be useful in cases where the supporting tower is relatively short and there may be a greater contribution to ground-level field strength from the lower part of the antenna. For main-beam exposure, where the field factor, F, may be closer to 1.0, the values in these tables are likely to be provide more realistic predictions of exposure at a given distance. This type of analysis may be required when nearby occupied structures or rooftops are in the path of the antenna's main beam. In such cases it may or may not be reasonable to include the surface reflection factor in equation (3). For that reason the values in tables labeled "No Reflection" were calculated without the reflection factor of 2.56 shown in Equation (1) and included in Equation (3).

Table 7. Distances for Single VHF-TV Antenna Compliance with FCC-Limits **(see text) (relative field factor = 1, assumes no surface reflection)**

Max. Visual ERP (kW)	Aural Power (% of Max. Visual Power)					
	5	10	12.5	15	20	22
	Meters from Center of Radiation (m)					
5	12.1 5.4	12.8 5.7	13.1 5.9	13.4 6.0	14.0 6.3	14.2 6.4
25	27.1 12.1	28.6 12.8	29.3 13.1	30.0 13.4	31.3 14.0	31.8 14.2
50	38.3 17.1	40.4 18.1	41.4 18.5	42.4 18.9	44.2 19.8	45.0 20.1
75	46.9 21.0	49.5 22.1	50.7 22.7	51.9 23.2	54.2 24.2	55.1 24.6
100	54.2 24.2	57.1 25.5	58.5 26.2	59.9 26.8	62.6 28.0	63.6 28.4
125	60.6 27.1	63.9 28.6	65.4 29.3	67.0 30.0	70.0 31.3	71.1 31.8
150	66.4 29.7	70.0 31.3	71.7 32.1	73.4 32.8	76.6 34.3	77.9 34.8
175	71.7 32.1	75.6 33.8	77.4 34.6	79.3 35.4	82.8 37.0	84.1 37.6
200	76.6 34.3	80.8 36.1	82.8 37.0	84.7 37.9	88.5 39.6	90.0 40.2
225	81.3 36.4	85.7 38.3	87.8 39.3	89.9 40.2	93.9 42.0	95.4 42.7
250	85.7 38.3	90.3 40.4	92.5 41.4	94.7 42.4	98.9 44.2	100.6 45.0
275	89.9 40.2	94.7 42.4	97.1 43.4	99.3 44.4	103.8 46.4	105.5 47.2
300	93.9 42.0	98.9 44.2	101.4 45.3	103.8 46.4	108.4 48.5	110.2 49.3
316	96.3 43.1	101.5 45.4	104.0 46.5	106.5 47.6	111.2 49.7	113.1 50.6

NOTES:

1. The top number indicates the height requirement for compliance with general population/uncontrolled limits. The bottom number indicates the height required for compliance with occupational/controlled limits.
2. For intermediate values interpolate between tabulated numbers or use equation (3)
3. The above values assume total visual ERP. Transmitting facilities using circularly polarized antennas must include sum of ERP in both horizontal and vertical polarizations.

Table 8. Distances for Single VHF-TV Antenna Compliance with FCC-Limits **(see text)** **(relative field factor = 1, assumes surface reflection)**

Max. Visual ERP (kW)	Aural Power (% of Max. Visual Power)					
	5	10	12.5	15	20	22
	Meters from Center of Radiation (m)					
5	19.4 8.7	20.4 9.1	20.9 9.4	21.4 9.6	22.4 10.0	22.8 10.2
25	43.4 19.4	45.7 20.4	46.8 20.9	47.9 21.4	50.1 22.4	50.9 22.8
50	61.3 27.4	64.6 28.9	66.2 29.6	67.8 30.3	70.8 31.7	72.0 32.2
75	75.1 33.6	79.1 35.4	81.1 36.3	83.0 37.1	86.7 38.8	88.1 39.4
100	86.7 38.8	91.4 40.9	93.6 41.9	95.9 42.9	100.1 44.8	101.8 45.5
125	96.9 43.4	102.2 45.7	104.7 46.8	107.2 47.9	111.9 50.1	113.8 50.9
150	106.2 47.5	111.9 50.1	114.7 51.3	117.4 52.5	122.6 54.8	124.6 55.7
175	114.7 51.3	120.9 54.1	123.9 55.4	126.8 56.7	132.4 59.2	134.6 60.2
200	122.6 54.8	129.2 57.8	132.4 59.2	135.6 60.6	141.6 63.3	143.9 64.4
225	130.1 58.2	137.1 61.3	140.5 62.8	143.8 64.3	150.2 67.2	152.7 68.3
250	137.1 61.3	144.5 64.6	148.4 66.2	151.9 67.8	158.6 70.8	161.2 72.0
275	143.8 64.3	151.6 67.8	155.3 69.5	159.0 71.1	166.0 74.2	168.8 75.5
300	150.2 67.2	158.3 70.8	162.2 72.5	166.0 74.2	173.4 77.5	176.3 78.8
316	154.1 68.9	162.5 72.7	166.5 74.4	170.4 76.2	178.0 79.6	180.9 80.9

NOTES:

1. The top number indicates the height requirement for compliance with general population/uncontrolled limits. The bottom number indicates the height required for compliance with occupational/controlled limits.
2. For intermediate values interpolate between tabulated numbers or use equation (3).
3. The above values assume total visual ERP. Transmitting facilities using circularly polarized antennas must include sum of ERP in both horizontal and vertical polarizations.

Table 9. Distances for Single UHF-TV Antenna Compliance with FCC-Limits **(see text)**
(aural power = 10% VERP; relative field factor = 1; assumes surface reflection)

Channel Range	Peak Visual ERP (kW)						
	250	500	1000	2000	3000	4000	5000
	Meters from Center of Radiation (m)						
14 - 17	115.5 51.6	163.3 73.0	230.9 103.3	326.5 146.0	399.9 178.9	461.8 206.5	516.3 230.9
18 - 21	112.6 50.3	159.3 71.2	225.2 100.7	318.5 142.4	390.1 174.5	450.4 201.4	503.6 225.2
22 - 25	110.0 49.2	155.5 69.6	219.9 98.4	311.0 139.1	381.0 170.4	439.9 196.7	491.8 219.9
26 - 29	107.5 48.1	152.0 68.0	215.0 96.2	304.1 136.0	372.4 166.6	430.0 192.3	480.8 215.0
30 - 33	103.0 47.1	145.7 66.5	206.1 94.1	291.5 133.1	357.0 163.0	412.2 188.2	460.8 210.4
34 - 37	103.0 46.1	145.7 65.2	206.1 92.2	291.5 130.3	357.0 159.6	412.2 184.3	460.8 206.1
38 - 41	101.0 45.2	142.9 63.9	202.0 90.3	285.7 127.8	349.9 156.5	404.0 180.7	451.7 202.0
42 - 45	99.1 44.3	140.1 62.7	198.2 88.6	280.3 125.3	343.3 153.5	396.4 177.3	443.1 198.2
46 - 49	97.3 43.5	137.6 61.5	194.6 87.0	275.1 123.1	337.0 150.7	389.1 174.0	435.0 194.6
50 - 53	95.6 42.7	135.1 60.4	191.1 85.5	270.3 121.4	331.0 148.0	382.2 170.9	427.4 191.1
54 - 57	93.9 42.0	132.8 59.4	187.9 84.0	265.7 120.9	325.4 145.5	375.7 168.0	420.1 187.9
58 - 61	92.4 41.3	130.7 58.4	184.8 82.6	261.3 118.8	320.0 143.1	369.5 165.3	413.2 184.8
62 - 65	90.9 40.7	128.6 57.5	181.8 81.3	257.1 116.9	314.9 140.8	363.6 162.6	406.6 181.8
66 - 69	89.5 40.0	126.6 56.6	179.0 80.1	253.2 115.0	310.1 138.7	358.0 160.1	400.3 179.0

NOTES:
1. The top number indicates the height requirement for compliance with general population/uncontrolled limits. The bottom number indicates the height required for compliance with occupational/controlled limits.
2. For intermediate values interpolate between tabulated numbers or use equation (3).
3. The above values assume total visual ERP. Transmitting facilities using circularly polarized antennas must include sum of ERP in both horizontal and vertical polarizations.

Table 10. Distances for Single UHF-TV Antenna Compliance with FCC-Limits **(see text) (aural Power = 10% VERP, relative field factor = 1, assumes no surface reflection)**

Channel Range	Peak Visual ERP (kW)						
	250	500	1000	2000	3000	4000	5000
	Meters from Center of Radiation (m)						
14 - 17	72.2 32.3	102.0 45.6	144.3 64.5	204.1 91.3	250.0 111.8	288.6 129.1	322.7 144.3
18 - 21	70.4 31.5	99.5 44.5	140.8 63.0	199.1 89.0	243.8 109.0	281.5 125.9	314.8 140.8
22 - 25	68.7 30.7	97.2 43.5	137.5 61.5	194.4 86.9	238.1 106.5	274.9 123.0	307.4 137.5
26 - 29	67.2 30.1	95.0 42.5	134.4 60.1	190.1 85.0	232.8 104.1	268.8 120.2	300.5 134.4
30 - 33	65.8 29.4	93.0 41.6	131.5 58.8	186.0 83.2	227.8 101.9	263.0 117.6	294.1 131.5
34 - 37	64.4 28.8	91.1 40.7	128.8 57.6	182.2 81.5	223.1 99.8	257.6 115.2	288.0 128.8
38 - 41	63.1 28.2	89.3 39.9	126.3 56.5	178.6 79.9	218.7 97.8	252.5 112.9	282.3 126.3
42 - 45	61.9 27.7	87.6 39.2	123.9 55.4	175.2 78.3	214.5 95.9	247.7 110.8	277.0 123.9
46 - 49	60.8 27.2	86.0 38.5	121.6 54.4	172.0 76.9	210.6 94.2	243.2 108.8	271.9 121.6
50 - 53	59.7 26.7	84.5 37.8	119.5 53.4	168.9 75.6	206.9 92.5	238.9 106.8	267.1 119.5
54 - 57	58.7 26.3	83.0 37.1	117.4 52.5	166.1 74.3	203.4 91.0	234.8 105.0	262.5 117.4
58 - 61	57.7 25.8	81.7 36.5	115.5 51.6	163.3 73.0	200.0 89.5	231.0 103.3	258.2 115.5
62 - 65	56.8 25.4	80.4 35.9	113.6 50.8	160.7 71.9	196.8 88.0	227.3 101.6	254.1 113.6
66 - 69	56.8 25.0	80.4 35.4	113.6 50.0	160.7 70.8	196.8 86.7	227.3 100.1	254.1 111.9

NOTES:

1. The top number indicates the height requirement for compliance with general population/uncontrolled limits. The bottom number indicates the height required for compliance with occupational/controlled limits.
2. For intermediate values interpolate between tabulated numbers or use equation (3).
3. The above values assume total visual ERP. Transmitting facilities using circularly polarized antennas must include sum of ERP in both horizontal and vertical polarizations.

Table 11. Distances for Single UHF-TV Antenna Compliance with FCC-Limits **(see text) (aural power = 22% VERP, relative field factor = 1, assumes surface reflection)**

Channel Range	Peak Visual ERP (kW)						
	250	500	1000	2000	3000	4000	5000
	Meters from Center of Radiation (m)						
14 - 17	128.6 57.5	181.8 81.3	257.1 115.0	363.6 162.6	445.3 199.2	514.2 230.0	574.9 257.1
18 - 21	125.4 56.1	177.3 79.3	250.8 112.2	354.7 158.6	434.4 194.3	501.6 224.3	560.8 250.8
22 - 25	122.5 54.8	173.2 77.5	244.9 109.5	346.4 154.9	424.2 189.7	489.8 219.1	547.6 244.9
26 - 29	119.7 53.5	169.3 75.7	239.4 107.1	338.6 151.4	414.7 185.5	478.9 214.2	535.4 239.4
30 - 33	117.2 52.4	165.7 74.1	234.3 104.8	331.4 148.2	405.8 181.5	468.6 209.6	523.9 234.3
34 - 37	112.5 51.3	159.1 72.6	225.0 102.6	318.1 145.1	389.6 177.8	449.9 205.3	503.0 229.5
38 - 41	112.5 50.3	159.1 71.1	225.0 100.6	318.1 142.3	389.6 174.3	449.9 201.2	503.0 225.0
42 - 45	110.3 49.4	156.1 69.8	220.7 98.7	312.1 139.6	382.2 170.9	441.4 197.4	493.5 220.7
46 - 49	108.3 48.4	153.2 68.5	216.7 96.9	306.4 137.0	375.2 167.8	433.3 193.8	484.4 216.7
50 - 53	106.4 47.6	150.5 67.3	212.8 95.2	301.0 134.6	368.6 164.9	425.6 190.4	475.9 212.8
54 - 57	104.6 46.8	147.9 66.2	209.2 93.6	295.9 132.3	362.3 162.0	418.4 187.1	467.8 209.2
58 - 61	102.9 46.0	145.5 65.1	205.8 92.0	291.0 130.1	356.4 159.4	411.5 184.0	460.1 205.8
62 - 65	101.2 45.3	143.2 64.0	202.5 90.5	286.3 128.1	350.7 156.8	404.9 181.1	452.7 202.5
66 - 69	99.7 44.6	141.0 63.0	199.3 89.1	281.9 126.1	345.3 154.4	398.7 178.3	445.7 199.3

NOTES:

1. The top number indicates the height requirement for compliance with general population/uncontrolled limits. The bottom number indicates the height required for compliance with occupational/controlled limits.
2. For intermediate values interpolate between tabulated numbers or use equation (3).
3. The above values assume total visual ERP. Transmitting facilities using circularly polarized antennas must include sum of ERP in both horizontal and vertical polarizations.

Table 12. Distances for Single UHF-TV Antenna Compliance with FCC-Limits **(see text) (aural power = 22% VERP, relative field factor = 1, assumes no surface reflection)**

Channel Range	Peak Visual ERP (kW)						
	250	500	1000	2000	3000	4000	5000
	Meters from Center of Radiation (m)						
14 - 17	80.4 35.9	113.6 50.8	160.7 71.9	227.3 101.6	278.3 124.5	321.4 143.7	359.3 160.7
18 - 21	78.4 35.1	110.8 49.6	156.8 70.1	221.7 99.1	271.5 121.4	313.5 140.2	350.5 156.8
22 - 25	76.5 34.2	108.2 48.4	153.1 68.5	216.5 96.8	265.1 118.6	306.1 136.9	342.3 153.1
26 - 29	74.8 33.5	105.8 47.3	149.6 66.9	211.6 94.6	259.2 115.9	299.3 133.9	334.6 149.6
30 - 33	73.2 32.7	103.6 46.3	146.4 65.5	207.1 92.6	253.6 113.4	292.9 131.0	327.4 146.4
34 - 37	71.7 32.1	101.4 45.4	143.4 64.1	202.8 90.7	248.4 111.1	286.9 128.3	320.7 143.4
38 - 41	70.3 31.4	99.4 44.5	140.6 62.9	198.8 88.9	243.5 108.9	281.2 125.8	314.4 140.6
42 - 45	69.0 30.8	97.5 42.8	137.9 60.6	195.1 85.6	238.9 104.9	275.9 123.3	308.4 137.9
46 - 49	67.7 30.3	95.7 42.8	135.5 60.6	191.5 85.6	234.5 104.9	270.8 121.1	302.8 135.4
50 - 53	66.5 29.7	94.1 42.1	133.0 59.5	188.1 84.1	230.4 103.0	266.0 119.0	297.4 133.0
54 - 57	65.4 29.2	92.5 41.4	130.8 58.5	184.9 82.7	226.5 101.3	261.5 116.9	292.4 130.8
58 - 61	64.3 28.8	90.9 40.7	128.6 57.5	181.9 81.3	222.7 99.6	257.2 115.0	287.5 128.6
62 - 65	63.3 28.3	89.5 40.0	126.5 56.6	179.0 80.0	219.2 98.0	253.1 113.2	283.0 126.5
66 - 69	62.3 27.9	88.1 39.4	124.6 55.7	176.2 78.8	215.8 96.5	249.2 111.4	278.6 124.6

NOTES:

1. The top number indicates the height requirement for compliance with general population/uncontrolled limits. The bottom number indicates the height required for compliance with occupational/controlled limits.
2. For intermediate values interpolate between tabulated numbers or use equation (3).
3. The above values assume total visual ERP. Transmitting facilities using circularly polarized antennas must include sum of ERP in both horizontal and vertical polarizations.